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03 APR. 2002

Modtaget

Laser system

This invention relates to a laser system.

The aim of the Multiple Cavity High Brightness Diffraction Limited Diode Laser concept is to squeeze the output power of free running multi-mode laser diodes into the lowest spatial angle as possible. The results are laser systems based on single stripe diodes, diode bars and diode arrays that produce diffraction limited high brightness optical outputs.

The output power of laser diodes is limited by the geometry of the active region of the emitter. This is due to the fact that the optical output intensity can damage the material of the lasing medium if the intensities reach a material depended level. Therefore high power laser diodes are forced into the use of large geometries as; wide single stripe emitters, which introduces effects of multi-mode lasing, or several wide emitters in bars or arrays. The multi-mode diodes distribute the optical output power over the number modes that overcome the lasing condition. These modes radiates from the emitter into space in different spatial angles. The total output is therefore none diffraction limited and with low brightness, relative to the optimum. The bars and arrays suffer from the same problems of none diffraction limited and low brightness outputs also, because they are build up of wide single stripe emitters.

International application WO 02/21651 discloses a laser system with a laser diode and an external cavity selecting a single spatial mode of a spatial light distribution.

However, the prior art involves the problem that, at high output powers, the optical power inside the laser diode may become so large as to damage the laser diode, thereby limiting the achievable optical output power.

This problem is solved when a laser system comprising

- an amplifier member including an amplifying medium;

- a first reflective member located on a first side of the amplifier member; and
- a second reflective member located on a second side of the amplifier member opposite the first side;

is characterised in

that the laser system further comprises a third reflective member located on the second side of the amplifying member and, during operation, cooperating with the second reflective member to control the spatial intensity distribution of the light distribution in the amplifying medium in a direction along the first and second sides of the amplifier member.

Consequently, by controlling the asymmetry of the light distribution inside the amplifying medium, the maximum achievable output power may be increased, thereby providing a laser system having a high brightness and an output beam with good coherence properties.

The first reflective member may be a coated rear facet of the amplifier member, e.g. a rear facet of a laser diode having a reflective coating. Other examples of reflective members include an external mirror or an external grating. Furthermore, the first reflective member may be divided in two or more reflective components, e.g. two external mirrors or gratings forming an acute angle between them, or a rear facet including two areas forming an acute angle between them.

The second and third reflective members may be external mirrors or gratings, or any other suitable reflective member. For example, the second and third reflective members may be respective areas of the front facet of the amplifier member, the areas forming an acute angle between them. Preferably, the areas are coated with a coating having a reflectivity which depends on the incident angle. Other examples of reflective members include a hologram.

The concept of the multi-cavity high brightness diffraction limited diodes lasers is to use a principle of multiple cavities to squeeze the power

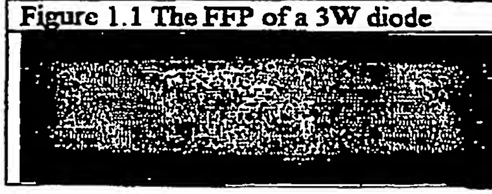
distributed on the giving number of existing modes into one mode, only. The laser then radiates a diffraction-limited beam with optimal high brightness. This technique can be applied to single stripe diodes, as well as diode bars and diode arrays.

The invention further relates to a combination of using diode lasers with more than two cavities, where the principles of selective mode feedback are used together with the principles of multi-beam interference to introduce gratings into an optical amplifier. This is further combined with grating introduction, amplification and stabilization in the optical amplifier by the principles of four-wave mixing. Finally this is combined with the introduction of transverse contributing cavities that creates asymmetry to the optical output and controls the strength of the gratings introduced into the amplifier. Here the optical amplifiers are single stripe emitters or emitters arranged as bars or arrays. This principle works one all wave lengths.

The Invention will be explained more fully below in connection with a preferred embodiment and with reference to the drawings.

<u>The Distribution of Diode Laser Output Power Into Multiple Modes</u>

The far-field profile (FFP) of a laser diodes output can be used to analyze the mode information of a laser diode. This is due to the fact that the FFP is the Fourier-transform of the laser diodes near-field profile (NFP). The NFP is the intensity distribution of the output measured on the surface of the emitter. The FFP of a multi-mode diode looks like an interference pattern of lines, where each of the fringes corresponds to a single mode.[1] Each mode is therefore seen to radiate into its own spatial angle. On figure 1.1 an example of a FFP is seen from a 3W diode with cavity lengths of 1000x200x1 μm (LxWxH). A CCD camera has recorded the image.

Figure 1.1 The FFP of a 3W diode	
	This FFP is shown as a false-colors image, where black/blue (dark gray values) correspond to low intensity and yellow/red (light gray values) to high intensity. The individual modes are seen

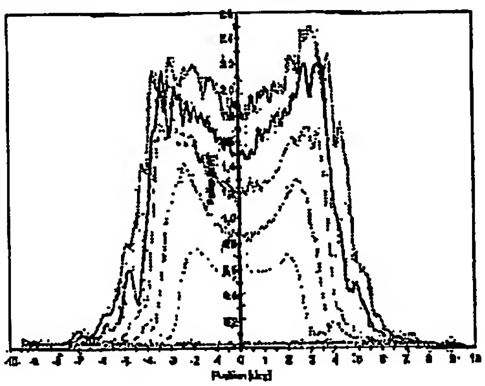
[1] The FFP is not an interference pattern, it just look like one.

03/04 '02 ONS 15:05 [AP/MT-NR 8388] 005

	intensity. The individual modes are seen as horizontal lines.

If the power distribution of figure 1.1 is examined more careful at a higher resolution, one can see the contribution from the single modes more clearly. Such information can be obtained by moving a narrow slit in front of a power detector through the image of figure 1.1. This is done for both for the vertical and the hortzontal direction. The result produces the curves seen on figure 1.2 and 1.3 respectively.

Figure 1.2. Vertical FFP, slow axis.



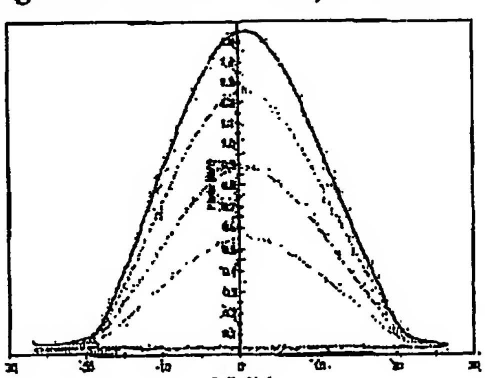
A vertical cross scanning through the center of Figure 1.1, results in the curve seen on figure 12. The different curves correspond to different levels of gain.

The x-axis reference is the radiation angle of the modes. The y-axis is the measured power. Each of the small peaks is the contribution from a single mode.

The profile her is referred to as the slow-axis (low divergence) FFP. This direction linked to the width of the diode.

From figure 1.2 it is seen that modes existing at high angles, until a certain limit, is amplified more than modes at small angles. One gets a M-shaped slow-axis FFP profile.

Figure 1.3. Horizontal FFP, fast axis.



A horizontal cross scanning through the center of Figure 1.1, results in the curve seen on figure 1.2.

The profile her is referred to as the fast-axis (high divergence) FFP. That is the direction liked to the height of the diode.

One mode is seen to exist her, only. This direction of the beam is therefore ideal to the aim of producing a diffraction limited high brightness output.

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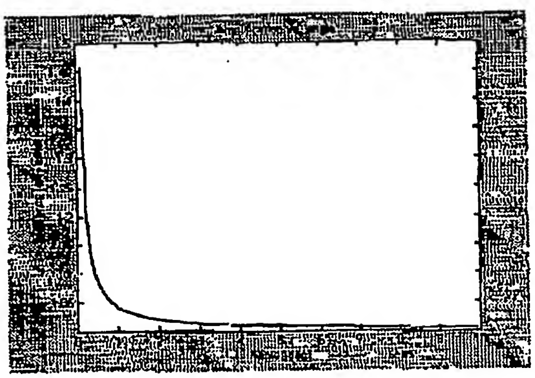
03/04 '02 ONS 15:05 [AF/MT-NR 8388] 006

From figure 1.1 to figure 1.3 it can be concluded that the properties of the slow-axis only differs from the aim of constructing a multiple cavity high brightness diffraction limited diode laser systems. The fast axis profile shows a contribution from a single mode only, already.

An important question to the principles used for these laser systems are, why the slow-axis profile looks as it does, seen figure 1.2? This profile does not agree with the expectations, in the classical point of view to lasers, where lasers is a one-dimensional devices with two mirrors that make up a cavity. In such a case almost all power should have been radiate through the center mode, at 0°, which clearly not is the case her. An example of such amplification vs. the angle of radiation is seen in figure 1.4.

Figure 1.4. Normal gain vs. angle



The number of possible reflections and thereby the length of the amplification path is highly controlling the ratio of amplification. A mode that exists at a high angle i.e. 5° gets almost no amplification, where as modes at small angles i.e. 0.1° gets high amplification.

If negative angles are included the curve can be mirrored in the y-axis. This corresponds to a FFP as seen on figure 1.2. It may even be rotated around the y-axis. If then seen from above one gets a FFP image like figure 1.1.

The case of figure 1.4 will results in a well-known Gaussian FFP profile as seen from i.e. a HeNe laser. It is seen that absolute no agreement can be found between the curve on figure 1.2 and the figure 1.4. The one dimension laser model does not work her.

Meanwhile the principles of multiple-beam interference explain the phenomenon seen in slow-axis direction on figure 1.2.

The Principles of Multiple-Beam Interference

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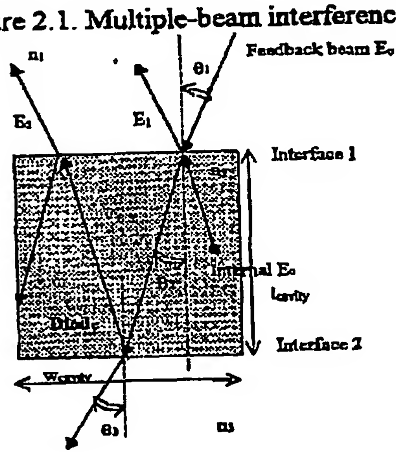
One can explain the phenomenon of increased amplification of high angle mode to be caused by the principles of multiple-beam interference, se figure 2.1 for an illustration. The interference pattern causes a grating to exist inside the lasing medium, due to diffusion of electrons. This diffusion is controlled by the contrast in the interference pattern. It can her be shown that the contrast in the interference pattern is almost washed out for modes at small angles, the center modes. Whereas the contrast rises for higher angles until the phenomenon of multiple-beam interference disappear due to the geometries of the cavities[2], se figure 2.2. Some modes will therefore get extra amplification because they exist at angles where constructive interference exists. Others are similar damped due to destructive inference. This phenomenon changes the properties of the gain due to the electron diffusion, also. The modes at high angles can therefore be amplified more that modes at low angles.[3]

Figure 2.1. Multiple-beam interference.



A starting beam E_0 can have its origin either from the out side the diode (i.e. feedback) or from inside the diode itself, by spontaneous or simulated emission.

In both cases the beam will propagate until it gets interaction with an interface, where parts of the beam will be reflected and transmitted. Inside the diode the beam can be amplified due to gain. The output beam, E_{Out} and the irradiance I_{Out} is then given by

$$E_{Out} = \sum E_N \quad and \quad I_R = |E_{Out}|^2$$

The theory used her can be used with the same effects on i.e. piece glass, because the starting beam does not have to originated from the lasing medium at all. The gain of the lasing medium is not required, too. Therefore

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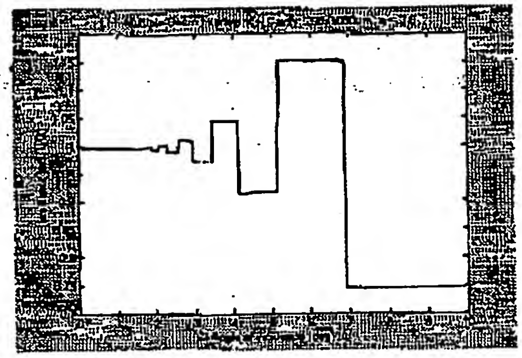
[2] The reason for using the word cavities and not cavity is that a diode laser in fact is buildup of three cavities: One in longitudinal-, one in slow-axis- and one in fast-axis direction. This point of view is essential to understand why a Multiple Cavity High Brightness Diffraction Limited Diode Laser can be build.

[3] This phenomenon is very essential to the understanding of optimal feedback of selective modes explained later on. Feedback at angles with constructive interference will succeed only.

it is shown that the laser diode is not a laser in itself in this configuration – it is an optical amplifier only.

Figure 2.2. Interference vs. angle (TM)

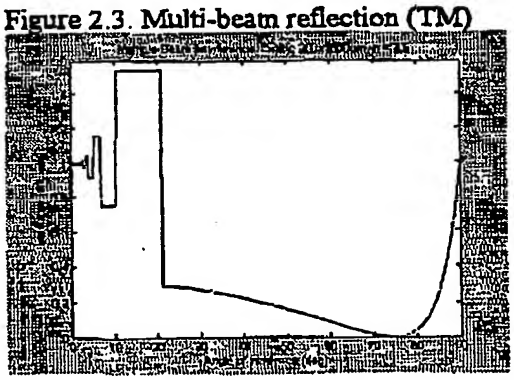


The intensity of the of the interference patterns drawn as function of the angle. This curve is done with out gain and losses. An external starting beam is used, similar to i.e. feedback. The angles are given as far-field angles. The diode medium is GaAs with the geometries of 1000x200x1μm. The reason for all the sharp corners is that the model takes into account interactions at surfaces, only. The sides to the left and the right of the medium are assumed to be a perfect absorber, also.

The figure 2.2 can be related to figure 1.2 as a wrap around curve. If gain is included the contrast is changed only. The case of figure 2.2 can then be compared with the case on figure 1.4. Both explain the effects of gain, but with different results.

The phenomenon of multiple interference stops when the angle becomes so high that no reflected beam can come back to the first interface. Normal reflection from a surface is then seen, se figure 2.3.

Figure 2.3. Multi-beam reflection (TM)



Above angles of 20° it is seen that no multiple-beams interference exists any longer. This limiting angle is controlled by the geometry of the diode (LxBxH), only.

One can recognize the curve above the limiting angle to be a reflection curve of a transverse magnetic (TM) beam. (Calculated from the Snell reflection coefficients).

The wrap around curve can be turned into a FFP like image, by sending an extra beam in from the left with respect to figure 2.1, se figure 2.4. Here the

03/04 '02 ONS 15:05 [AF/MT-NR 8383] 009

center value, that equals I0, is chosen to equal the center value of the measured curve that crosses the y-axis at 1.5, at figure 2.5. The size of the gain parameter is used to fit the contrast. One have to keep in mind that figure 2.4 is not a real FFP, but a gain controlling effect. The similarity is how ever conversing, if one thinks of the curve on figure 2.4 to be the warp around curve to figure 2.5. This lead to the conclusion, that the effects of the multiple-beam interference are responsible for the slow-axis FFP M-shape of wide single stripe diodes. So far all experimental FFPs seen obeys this theory.

Figure 2.4. Calculated far-field profile.

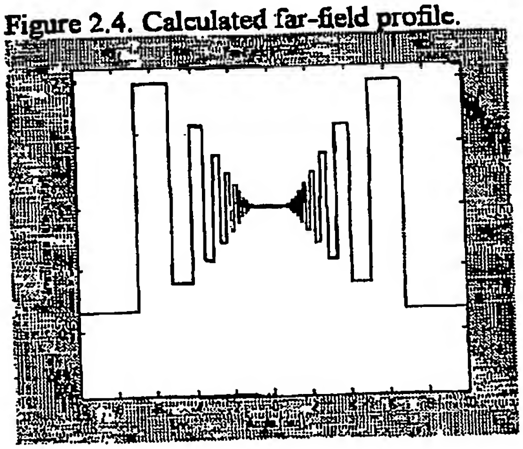
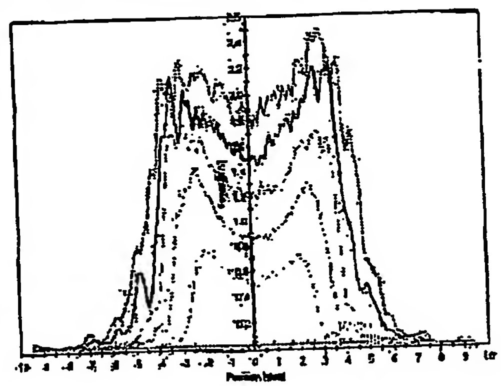


Figure 2.5. Real diode far-field profile.



One can claim that the coherence properties of the beams are not good enough to make such interference patterns - that might be true. Meanwhile this doesn't matter because the effect of 4-wave mixing takes into account this problem, and further it stabilizes this effect. See the description in chapter 3.

On figure 2.5 it can be noticed that asymmetry exist around the y-axis - modes to the right is amplified slightly more than modes to the left. This property is not included in this multiple-beam description. The phenomenon is meanwhile included in the theory of transverse contributing cavities, as described in the chapter 4.

One may have noticed also that the curve on figure 2.5 has an error. The interference effects between the two starting beams that travel in exactly the opposite direction of each other are not included. The effect is meanwhile

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03/04 '02 ONS 15:05 [AP/MT-NR 8383] 010

that the contrast in the interference pattern is increased. Further they couple to each other through 4-wave mixing, which makes the perfect properties of coherence for the creation of interference and thereby the gratings similar to those of the multiple-beam interference. Thereby these two effects contribute, to the same grating. This process is started by the multiple-beam interference that generates the first grating in which four-wave mixing can take place.

A natural question is now regarding basic theory of interference, what happens if the amplitudes of the two opposite traveling beams not are equal. The quick answer is that the contrast on the interference pattern is changed. In this case where i.e. one beam is unity in amplitude and the other is zero, one should basically not get any interference, but because of the multiple-beam interference the interference will exist any way. But it will represent the minimum contrast possible. If the two beams have the same intensity maximum contrast will exist. Therefore twice the contrast of the single beam case can be reached. This contrast is so high that modes above, in this case 4°, are damped so mush that practical no modes can exist above this limit. This effect can be seen at figure 2.5, too. The more sophisticated answer is that the output becomes asymmetric as described later on in the chapter 4, the theory of transverse contributing cavities.

In the following, the multiple beam interference will be described in greater detail.

The Amplification inside a Laser Diode Cavity

Light that is amplified inside a laser diode cavity can have its origin from spontaneous emission, stimulated emission, or it can be light reflected back into the cavity by an external cavity. I all cases the amplification is depended on the length of the amplification path and the out coupling at the cavity mirrors. Inside the cavity of multi-mode diodes modes exists at different angles and they are reflected multiple-times inside the cavity, as sketched in figure 2.6. Therefore different modes have different amplifications paths.

The basic amplification as function of the amplification length can be can be

Figure 2.6. Amplification path in cavity.

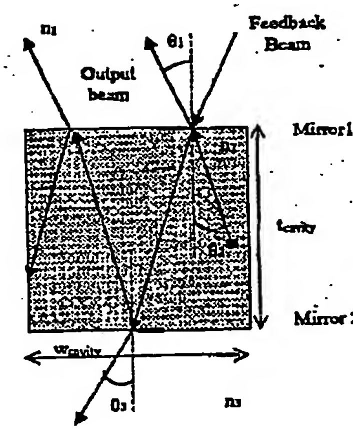
03/04 '02 15:12 FAX +45 39 48 81 91 -- HB&B.I&R 009

expressed as

$$I(L) = I(0)e^{g(\nu)L} \quad (1)$$

Where I is the irradiance, $g(\nu)$ is the gain per length for a frequency ν and L is the length of the amplification path. [2]

Manny reflection inside the diode cavity therefore results in a high amplification because of a long amplification path. This corresponds to small angles relative to the surface normal.



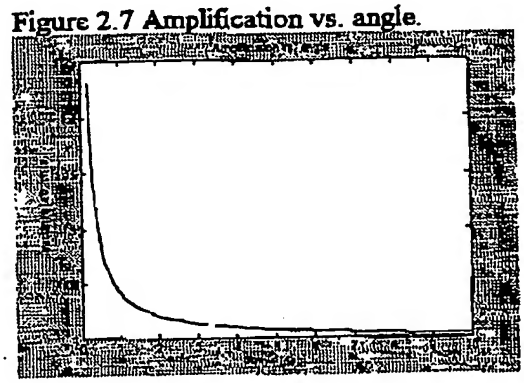
If the amplification is calculated from the path given by the number of possible reflections for a given angle, then the irradiance as function of the angle can be plot as seen in figure 2.7.

The gain medium is assumed to be GaAs with the dimensions 1000 x 200 um. $I(0) = 1$ and $g(\nu) = 1$ per meter (10 times threshold).

It is seen that small angles results in the highest amplification. Therefore multi- mode diodes must emit most power in the modes closest to 0°! The beam divergence must also be very small.

(Angels is referenced to the far-field)

Figure 2.7 Amplification vs. angle.

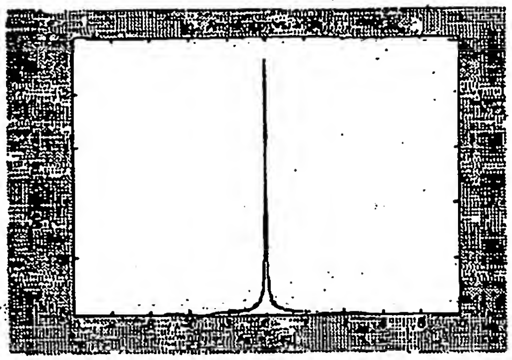


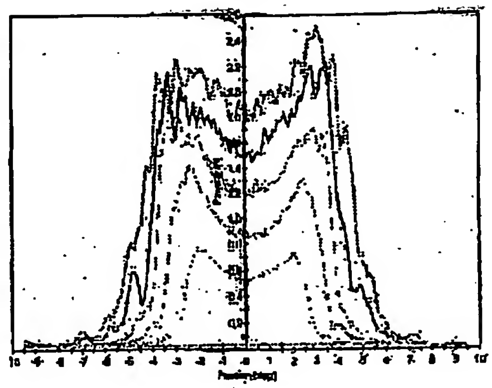
The far field profile of such a diode should therefore look like the curve in figure 2.8. Here all modes have to exist below this amplification curve. At figure 2.9 a far-field profile of a real diode with the curves made up by the existing modes. This diode has the same dimensions and properties as the one in figure 2.8. The diode is shown at different levels of gain.

Figure 2.8. Calculated far-field profile.

Figure 2.9. Real diode far-field profile.

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 012





It is clear that these two cases not can be related to each other at all. A real diode is not depended on the gain inside the cavity medium only, but also on something else.

The curve on figure 2.8 is of cause the aim of all laser constructions. Therefore the aim her is to change the construction of the laser in figure 2.9, or manipulate it to run and work in a different way until the result of figure 2.9 is obtained. This is exactly what is described in the next sections.

Hence, the normal simple gain per distance calculations is not valid for wide single stripe diodes. It is clear that no agreements between experimental and theoretical results exist. Therefore more advanced modelling techniques have to be included.

The next section therefore explains why a real diode behaves different from what normal is assumed. The introducing of multi-beam interference does this.

<u>The Multiple-Beam Interference inside a Laser Diode Cavity</u>

When a beam with the origin from either the inside of the diode or from feedback made by an external cavity, effects of multiple-beam interference will exist inside the diode cavity. These effects are seen as induced gratings caused by the interference patterns. The electrons in the diode medium are forced into none-uniform distributions because of the interference pattern. The interference can be either constructive or destructive. The contrast in

03/04 '02 15:13 FAX +45 39 48 81 91 HBSB.LSR 011

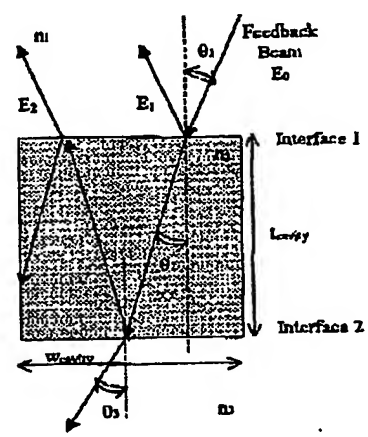
these patterns is responsible for the electron distribution, and thereby the gratings. The electron distribution is related directly to the index of refraction, and the properties of amplification.

The simplest case of a description is to assume that the diode is at threshold, loss equals gain. Further it is assumed that the origin of the light is externally. This corresponds to the well-known case of multiple-beam interference in a piece of glass, as illustrated in figure 3.1. (see e.g. Introduction to optics, F. L. Pedrotti, S.J. and L. S. Pedrotti, ISBN 0-13-016973-0)

The parameters important to multi-beam interference are the θ_1 angle of incidence, t_{cavity} the thickness and w_{cavity} the width of the cavity medium, and n_x the indices of refraction.

The multiple beams have originated from a single beam and the multiple beams are therefore coherent, in the ideal case. Close to the normal incidence the beams E vibrations are nearly parallel, too. The angles for feedback and normal beam divergence from a free running diode should be noticed her to exists at small angles $\theta_1 <$ 7°.

Fig. 3.1. Multiple-beam interference



In the following subsection the effect of multiple-beam interference is calculated for the case shown in figure 3.1.

Calculation of the Multiple-Beam Interference Effects:

Suppose that the electric-field propagating through the diode medium can be described as $E = E_0 \exp(i\omega t)$, and the phase difference between successive reflected beams is given by (see e.g. Introduction to optics, F. L. Pedrotti, S.J. and L. S. Pedrotti, ISBN 0-13-016973-0):

$$\delta = k\Delta, \quad where \quad \Delta = 2n_2 t\cos\theta_2 \qquad (1)$$

The N'th beam returned into medium 1 by reflection from the cavity can then be written as

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 014

$$E_N = \left(t_{1d} t_{1u} r_{2d}^{(N-1)} r_{1u}^{(N-2)} E_0\right) e^{i(\omega t-(N-1)\delta)},\ for\ N>1 \qquad (2)$$

This is not valid for the E1 field because it never enters medium 2. This field is meanwhile given by

$$E_1 = r_{1d} e^{i\omega t},\ for\ N>1 \qquad (3)$$

In these formulas the t's is the transmission coefficients and r's is the reflection coefficients for the interface between the different mediums. The subscript d means that the beam is travelling downwards relative to figure 3.1, and subscript u means upwards. By introducing the relative refractive index $m_1d=n_2/n_1$, $m_1u=n_1/n_2$ etc. and by the use of Snell's law the coefficients can be written with respect to the transverse electric TE and the transverse magnetic TM mode as:

$$\begin{aligned}
TE.\quad & r=\frac{E_r}{E}=\frac{\cos\theta-\sqrt{n^2-\sin^2\theta}}{\cos\theta+\sqrt{n^2-\sin^2\theta}} \\
TM:\quad & r=\frac{E_r}{E}=\frac{n^2\cos\theta-\sqrt{n^2-\sin^2\theta}}{n^2\cos\theta+\sqrt{n^2-\sin^2\theta}} \\
TE:\quad & t=\frac{E_t}{E}=\frac{2\cos\theta}{\cos\theta+\sqrt{n^2-\sin^2\theta}} \\
TM:\quad & t=\frac{E_t}{E}=\frac{2n2\cos\theta}{n^2\cos\theta+\sqrt{n^2-\sin^2\theta}}
\end{aligned} \qquad (4)$$

Most cases will include the TM mode only. The total reflected beam is then given by

$$E_R = E_1 + \sum_{N=2} E_N = r_{1d} E_0 e^{i\omega t} + \sum_{N=2}^{End} t_{1d} t_{1u} r_{2d}^{(N-1)} r_{1u}^{(N-2)} E_0 e^{i(\omega t-(N-1)\delta)} \qquad (5)$$

The transmitted E-field is not included here, it is considered to be a useless loss, because it does not contribute to the lasers output beam at all.

This actual effects seen at a detector is the irradiance given by

$$I_R = |E_R|^2 \qquad (6)$$

03/04 '02 15:14 FAX +45 39 48 81 81 HB&B.LSR 013

The effects of multi-beam interference can therefore be shown through a numeric example.

An Example of Multi-Beam Interference:

For an incident beam in TM-mode and diode cavity dimensions at i.e. 1000x2um no multiple-beams can exist at angles > 0.1°. The reflection from interface 1 will therefore make up the reflected irradiance IR alone, se figure 3.2. This case returns the well-known TM-reflection curve, seen at figure 3.2 (see e.g. Introduction to optics, F. L. Pedrotti, S.J. and L. S. Pedrotti, ISBN 0-13-016973-0). If the cavity dimensions are changed to 1000x200um several internal reflections will contribute to the IR, see figure 3.3.

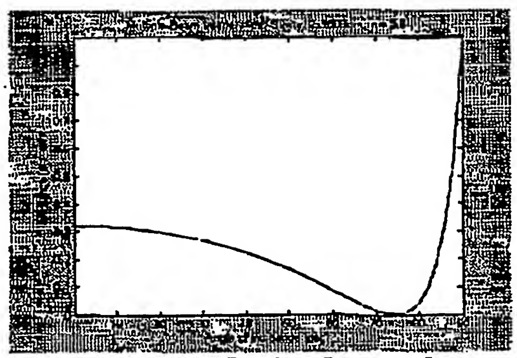


Figure 3.2. TM reflection from surface.

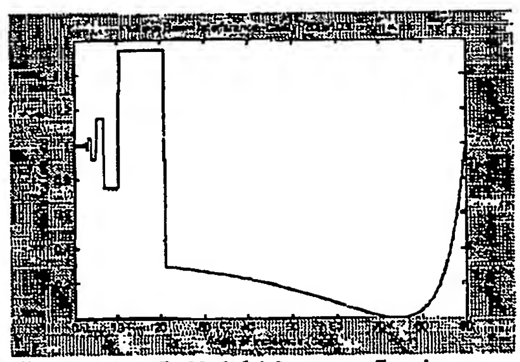


Figure 3.3. TM Multi-beam reflection.

Conditions:
Wavelength: 830nm, TM-mode, I = 1 arb. unit.

- The medium 1 is assumed to be air: n_1=1
- The medium 2 is assumed to be GaAs: n_2=3.6, cavity 1000x2/200um (Length/Width), no amplification or internal losses are included.
- The medium 3 is a high reflecting mirror (98.6%): ~ n_3 = 1000
- Angle are related to the far-field.

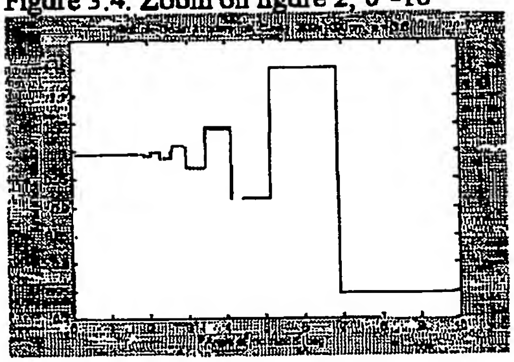
To investigate the interesting region (0°-10°) on figure 3.2, se figure 3.4 for a zoom.

What we seen is actually the amplitude of the reflected beam at different angles, where the incident beam had an irradiance I_0 = 1. Due to the

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 016

interference the power distribution is changed. Some modes are natural suppressed, whereas others are amplified. This leads to the conclusion that some angles of incidence/feedback have more effect than others, also. Almost no changes are seen at modes near 0° to 2°. Modes at 2° to3° is slightly more amplified or subdued. At 3° to 5° the effect is even clearer and above 5° the effects is really strong, tens of percent.

Figure 3.4. Zoom on figure 2, 0°-10°



Dramatically events are now seen to exist. Every event corresponds to an introduction of a new component E_N contributing to the irradiance I_R. The limiting angle of this phenomenon is seen to be around 20°, in this case. Above this angle no multiple-beams can exist and E_1 contributes to I_R, only. This limiting angle is controlled by the ration between the cavity width and height.

Including the Gain Effect:

The next question is natural, what happens if gain is included? Multiplying each field E_N by a gain factor, which included the gain effects since the E_{N-1} field, se figure 4.

Figure 3.4. Zoom on figure 2, 0°-10°

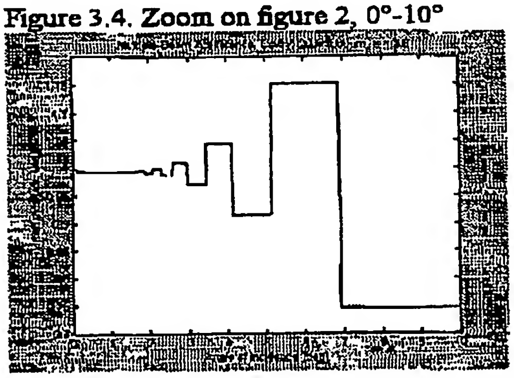
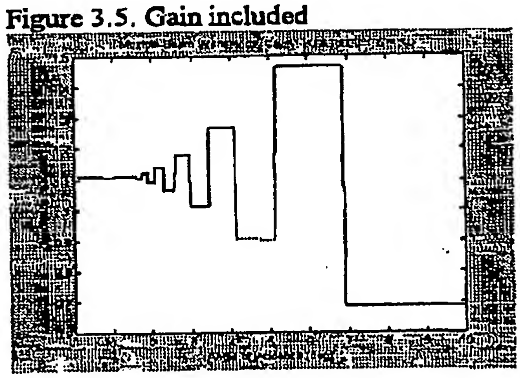


Figure 3.5. Gain included



The only effect of the gain is seen to exist in the contrast of the interference pattern. The contrast and thereby the strength of the effects of the multi-beam interference is therefore seen to be controlled by the gain alone. Whereas the angle of incidence controls if constructive or destructive

03/04 '02 15:15 FAX +45 39 48 81 91 HB&R.L&R 015

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 017

interference is obtained. Therefore higher gain and higher angles of incidence returns more angle depended amplification.

An important issue is here that this model does not distinguish the laser diode from the external cavity. Therefore one cannot talk about that the diode is the laser and a feedback system is an external cavity. The laser is both the diode and the external cavity. As it will be shown later on the diode is an amplifier that amplifies what the laser is tuned for, only. The properties of the I0 is therefore very important for the behaviour of the laser

The far-field profile:
All modes of a multi-mode diode have to exist below the interference gain curve of figure 3.5. Therefore an approximated far-field profile (FFP) of a diode can be calculated from the knowledge of the geometry, material, gain and I_0. The number of modes, mode spacing and mode width is not included, yet. But the modes amplitudes are herby described, se figures 3.6 and 3.7.

Figure 3.6. Calculated far-field profile.

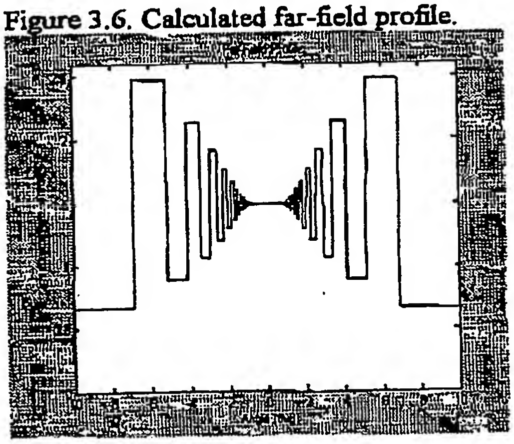
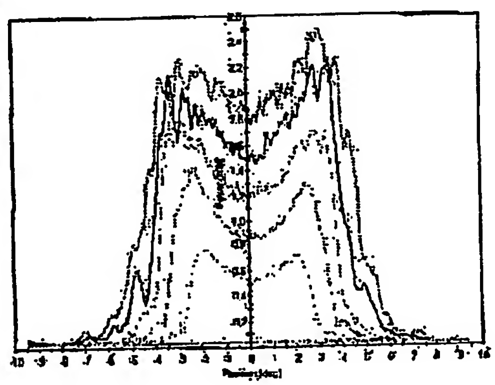


Figure 3.7. Real diode far-field profile.



The I_0 and gain is her chosen to fit the real diode FFP that crosses the y-axis in 1.5 [arb. units]. The irradiance I_0 is chosen from figure 3.7 and the gain parameter is used for fitting - it is not calculated from the physical properties.

Compared with the normal simple gain per distance calculations done earlier, it is seen that this way of doing amplification calculations is very close to reality.

03/04 '02 15:16 FAX +45 39 48 81 91 HB&B.I&R 016

Meanwhile it is important to notice what this model does not describe:

- Diverges of the beam that increases with the gain is clearly an effect not included. The boundary conditions of the beam remain therefore unknown to this model.
- Details on the individual modes are not included either.
- Temperature effect due to i.e. gain etc. is not included.
- It can be discussed if the coherence length of the multi-beams is long enough etc., because these properties are assumed to be ideal. If this comes to a problem the model falls because interference will not exist then. It should therefore be noticed that this model is enhanced in one of the next section to include the properties of 4-wave mixing. These effects compensates totally for this weak point.

What can this model be used for?

- The effect causing the M-shape far-field profile of wide single stripe diode is herby known to be multi-beam interference.
- It is known why the high angle modes is amplified more that the centre modes when the gain is increased.
- Diodes geometry can be optimized for the use in a feedback system.
- Optimal angles for feedback can choose.

The basic theory to explain the far-field profile of a wide single stripe diode is herby known. The optimization parameters to design diodes for feedback systems, and the optimal angles for feedback is herby know, too. Next the boundary conditions have to be included.

<u>Including the Boundary Condition for the Mode Existence:</u>

In principle a large/infinite number of modes can inside wide single stripe diode because the geometry. In fact it is seen that this not is the case in reality. The effect of "hole burning" limits this number (see e.g. Lasers, P. W. Milonni and J. H. Eberly, ISBN 0-471-62731-3). The remaining modes have to overcome the threshold condition, which limits the number of modes further. Therefore a result of raising the gain is that more modes can

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 018

overcome this condition. As known from the interference gain curve it become easier and easier to get gain as the angle of incidence grow, and it can become harder and harder also – this depends on the introduced interference pattern/grating.

Therefore the modes at high angles are very fast to show up in the beginning as the gain is raised. This process can go on until the very strong destructive interference is created i.e. above 4° at figure 7 her 50% of the zero angle gain is here removed, whereas the modes below 4° get 50% extra gain. Therefore it is seen that the angle of divergence is limited to 4°. The boundary conditions will therefore work as function of the gain and the geometry. This function works in clear steps. This agrees with the fact that diodes in the same power range always have almost the same angles of divergences – one have to remember that the power is limited by the geometry. The angle at which the contrast equals the centre gain is from now assumed to be the boundary condition.

Including the details of the modes leads to the final model of the free running diode and the aim of the mode selective feedback for squishing the total amount of power into as small spatial angle as possible.

Including the Mode Details:

When looking at figure 3.7 one could get the idea that the mod spacing changes with the angle of incidence. This does not agree with basic laser theory, where the mode spacing always has to obey the frequency spacing condition c/2L (see e.g. Lasers, P. W. Milonni and J. H. Eberly, ISBN 0-471-62731-3). The reason it looks different is due to the multi-beam interference that takes out a larger and larger number of modes each time a new destructive interference fringes occurs as the angle of incidence grow. The remaining modes in the constructive interference regions therefore look as they were a single mode but most of them are several modes close together. Here one has to keep in minds that figure 3.7 do not represent a frequency scale but an angular mode distribution into space – the far-field. Every one of these modes oscillates on their own frequency, separated by its neighbour

03/04 '02 15:17 FAX +45 39 48 81 91 HB&R.L&R 018

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 020

mode by the frequency c/2L. This give rise to a high amount of modes, but most of them never comes above threshold.

Following modes will be related to the angle rather than the frequency because working with far-fields does the practical easier. Second the aim is to change the work of the diode by use of the far-field, where single modes have to be located.

Free Running Diodes:
A free running laser diode will make multiple-beam interference also. The difference is just that the diode can make its own beam independed on the feedback beam. Due to effects like "whole-burning" some beams will die out and other will live. These effects cause modes to exist. This mode is amplified differently depending on the gain, angles etc. and the multiple-beam interference, also.

The amplification becomes therefore depended on the angle of incidence θ1 due to destructive and constructive interference at different angles. This effect is therefore highly important to a multi-mode diode because modes exist at different angles, too. The modes will therefore be amplified differently.

Including the Amplification in the Diode Medium:
A major difference between having an i.e. a glass plate as medium 2 and having a laser diode is that the laser diode can make an amplification inside the process of multiple-beam interference. Each time the incident field E0 had a loss due to an interaction with the interfaces the internal reflected beam starts to be amplified on the way to the next interaction with a surface. The amplification can be expressed as

Long amplification lengths therefore exist at small angles of incidence, which correspond to a high number of multiple-beams. See figure 3.4.

If a loss at an interface is larger that the amplification since the last surface loss, the result is still a die out of the beam. Opposite the process runs wild.

03/04 '02 15:17 FAX +45 39 48 81 81 HB&B.L&R 019

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 021

Depending on the angle of incidence the feedback beam is internally reflected N times inside the cavity medium. Because of the gain inside the cavity medium the beam is amplified different for each angle of incidence. This is due to the differences in the optical path length. Longer path more amplification:

The curve at figure 3.4 is simulated at threshold, no losses inside medium 2. Losses exist at the interfaces by reflection and transmission, only. A question will be what effects does a gain inside the medium 2 have?

Gain does not change the position of the fringes of the interference grating but it changes the contrast indeed, se figure 3.5.

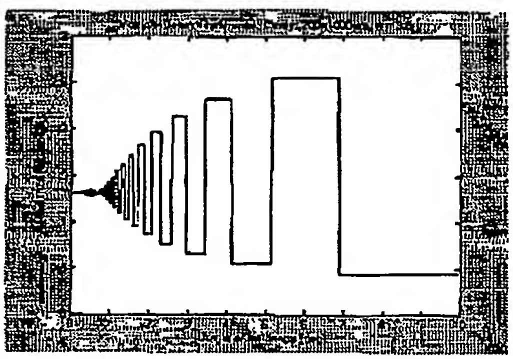


Figure 3.8

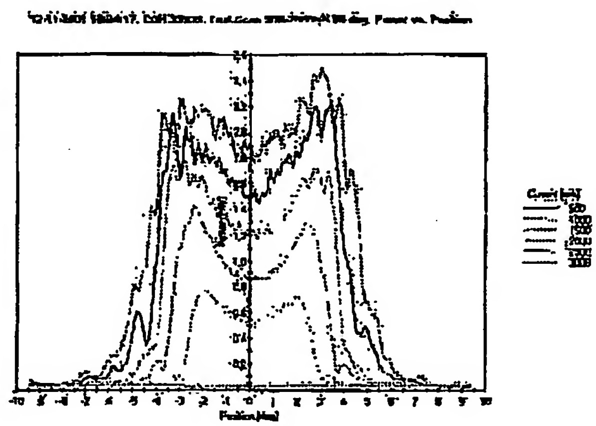


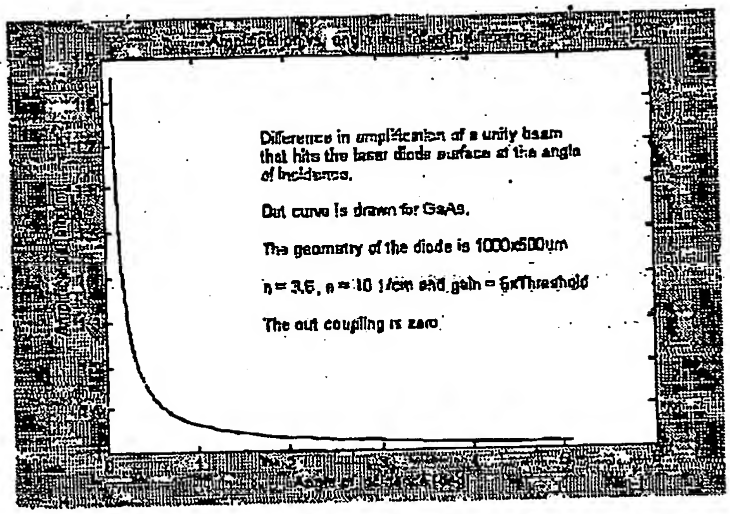
Figure 3.9

Figure 3.8 shows even more gain than figure 3.5. Compared with figure 3.9 that shows a free running diode with the same data as used in figure 3.8, some similarities can be seen: Sides are chopped off around 4°. The 2° in the centre is amplified equally and less that the modes between 1° and 4° from the centre. The amplification increases similar in the range 1°-4°. The contrast between neighbour modes in this range is high, too.

The condition for high amplification is seen to exist at the small angles of incidence, too.

03/04 '02 15:18 FAX +45 39 48 81 91 HB&B.L&R 020

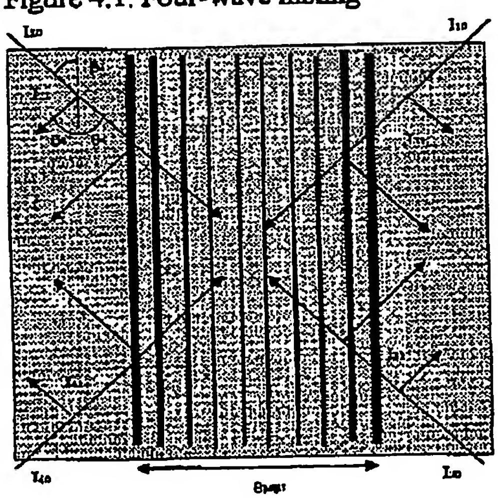
03/04 '02 ONS 15:05 [AP/MT-NR 8388] 022



The Theory of Four-Wave Mixing

Four waves that obey the conditions of making interference can contribute to the none-linear effect of four-wave mixing. Four-wave mixing can exist in almost any materials with a crystal structure among these laser diodes, also. In four-wave mixing a grating is introduced due to interaction between the four waves. In this grating the beams can diffract, so power is transferred from one beam to an other, se figure 4.1.

Figure 4.1. Four-wave mixing



The figure 4.1 illustrates two effects on top of each other. The dark vertical lines is the grating caused by multiple-beam interference. The angles θ_{MBI} correspond to this effect and thereby figure 2.2.

The other effect is the four-wave mixing with the starting beams I_{N0} that enters then medium under an angle related to θ_{MBI}. The angle of all four beams is here assumed to be the equal. Parts of these beams diffract into the beams I_{N1}. The sizes of the beams I_{N1} grows and grows through the propagation of the beams through the medium, because of the diffraction.

03/04 '02 15:18 FAX +45 39 48 81 91 HB&B.LRR 021

A question is now, where does the four beams come from? As in the case of the multiple-beam interference the beams can originate from both outside an inside the medium.[4] Lets assume that case is similar to the one of figure 2.1. I_{10} is the starting beam. This beam is reflected at the interface 2 and become the starting beam I_{30} and so on. Parts of the beam I_{10} is diffracted into the beam I_{11} this beam can be taken in to be the beam I_{20}. Parts of the beam I_{30} is diffracted into the beam I_{31} that can be take in to be the beam I_{40}. Beam I_{11} diffracts also but this can be seen as a contribution to the beam I_{10}. Every one of the beams is linked to each other. Therefore beams travelling left is depended on the beam travelling right, and beams travelling up and down is therefore depended on the beams travelling left and right, also.

The effects of this link between left and right traveling waves is assumed to minimal to a free running diode, because many modes exist at the same time, and therefore washes out the gratings. If one mode gets much more gain that the rest of the modes i.e. because of selective mode feedback as described below, the grating can be made very strong and the coupling coefficient will increase. This will lower the gain for the rest of the modes therefore more power of the total power will be concentrated in the selected mode. One should here notice that four-wave mixing is a higher order effect that normally will be weaker than a linear effect like the multiple-beam interference.

Four-wave mixing can therefore be concluded to be an effect that amplifies and stabilizing the gratings that are important for gain control in this laser system.

<u>The Theory of Transverse Contributing Cavities</u>

If it is assumed that the amplitudes of beams travelling left and right with reference to figure 3.1 is controlled by a cavity perpendicular to the one between interface 1 and interface 2 the effects of the asymmetry can be explained. This cavity will like a normal laser cavity has two different

[4] Once again it is a fact that the effects used in this paper can work on almost any mediums i.e. piece of glass. Therefore the laser diode is her independed amplifier, only.

coefficients of reflectivity, which control the size of the two beams.[5] On figure 4.1 and 4.2 is shown the FFP of two similar diodes. The one on figure 4.2 is seen to be more asymmetric as the one on figure 4.1.

Figure 4.1. Almost symmetric FFP

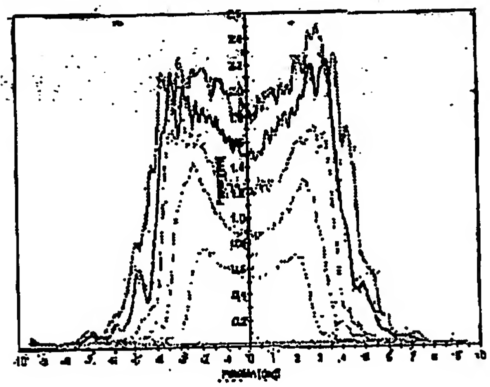
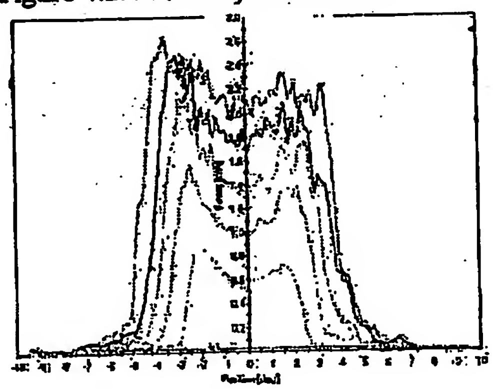


Figure 4.2. More asymmetric FFP



In practice one seen that asymmetry is a natural effect that exist on free running diodes, also. The aim her is to use this effect and optimize it for use in this application. Total control over this effect is therefore wanted.

Figure 4.3. Beam with same amplitude

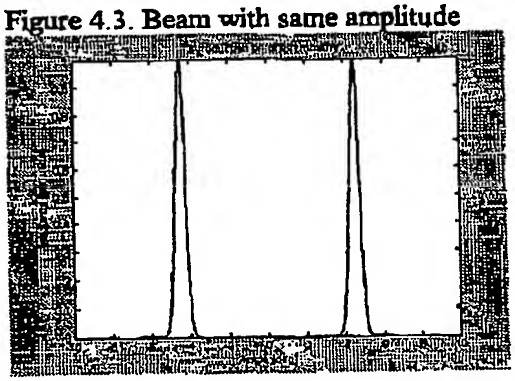
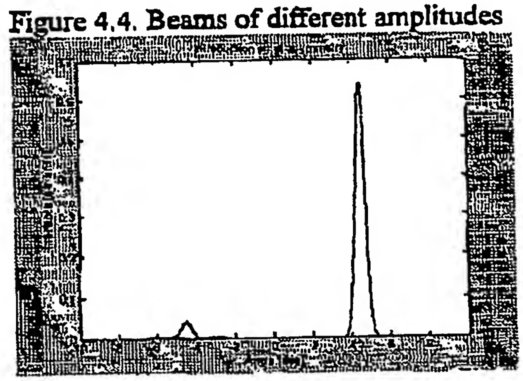


Figure 4.4. Beams of different amplitudes



If the assumption above is use in a mathematical model one can get the curves on figure 4.3 and 4.4, which is drawn for one mode only. The one in figure 4.3 have the same coefficient of reflection on both cavities, whereas

[5] One could just make the assumption that the case handles the case where two free beams is entering from left and right respective, also. Meanwhile this is not the case used in chapter 6 regarding feedback.

03/04 '02 ONS 15:05 [AR/MT-NR 8388] 025

the on one on figure 4.4 have different ones. It is seen that asymmetry can be totally controlled by this effect.

A question is now, how can this effect be controlled in practices? In diode production every thing is done to avoid such effects. This is done basically in two ways: either by making the reflective so small as possible on index guided diodes, or by using gain guided diodes – these can however get asymmetric, too. If one want to changes this properties the easiest way is therefore to use a special form of external cavity that introduces such an asymmetry. Then standard diodes can be used for the system. Special diodes with this feature included can be produced as well.

<u>The Cavity Systems</u>

The aim of this chapter is to link the effects of the three phenomenons described in chapter 2, 3 and 4 together through the construction of a laser system that involves more than 2 mirrors. These constructions of laser systems have to control the ration of the coupling of between the three basic phenomenons, as well.

The introduction of angle depended gain is done by the creation of gratings due to interference caused by both the multiple-beam interference and the four-wave mixing, as described above. Therefore, one has to control the angle of incidence to select the optimal angles for amplification, as described above. This could i.e. be the alignment of a feedback mirror.

The contrast in these interference patterns and thereby the strength of the gratings are controlled not only by the angle of incidence but also of the ration between the intensities of the beams travelling left and right, with respect to the theory described above. Further these beams control the asymmetry of the FFP, too. Therefore these laser systems have to control the ration between the intensity of the beams that travels left and right. Changing the reflectivity of a feedback mirror can i.e. do this.

A large number of variants of such a laser system can be build by vary the number of mirrors can thereby the number of cavities. Common for them all will be the combination of the three basic phenomena and the use of at least

03/04 '02 15:21 FAX +45 38 48 81-81 HB&B,L&R-- 024

2 mirrors. These laser systems can be build up of external mirrors as well as internal mirrors, that is made up of the geometry of the diode. Mirrors can here be holograms or gratings, too.

In the following it is assumed that one mode exist only for simplicity. This mode can exist at any angle of incidence. The case of selective mode feedback that leads to the case is described below.

Figure 5.1 shows a simple construction of a laser system that works as described above. Optics as lenses is left out here, too. This diode is made up of the cavities between the mirrors/surfaces R_1 and R_2, and R_3 and R_4. The R_3 and R_4 is assumed to be none reflecting. R_2 is 100% reflecting and R_1 is i.e. 30% reflecting. This drawing holds the slow-axis contribution only. There is of cause a cavity into the plane of the paper, too – the fast-axis.

The mirrors R_5 and R_6 can be adjusted to do feedback that selected angle of incidence. The reflectivity of the mirrors can be changed to control the ration between the intensity of the beams travelling left and right respectively. Thereby are the linking between the three phenomena done, and the ration of the linking also.

Figure 5.1. Cavities of laser system

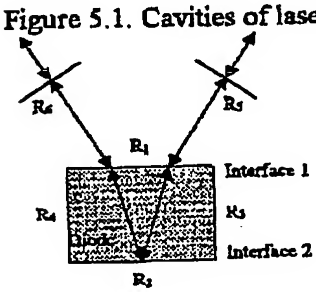
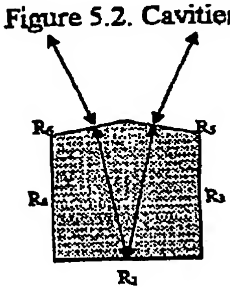


Figure 5.2. Cavities in a diode itself



This linking is done in this way: The FFP of the free running diode tells that the mode with the highest amplification at figure 1.2 is the best one for feedback, it have is placed I a region with constructive interference – therefore the high amplification.

03/04 '02 ONS 15:05 [AF/MI-NR 8388] 027

The cavity important for the asymmetry effects is the cavity between the surfaces R_3 and R_4. This cavity can meanwhile be seen as a virtual cavity in the cases where standard diode is used as beam source, because normally everything is done her to make the reflectivity zero. A new cavity is therefore introduced between R_5 and R_6 via R_2. These mirrors have both a horizontal and vertical contribution.

Above, the none-linear effect four-wave mixing did the coupling between the left and right traveling waves. The mirrors R_5 and R_8 introduce her a linear coupling, also. Thereby the effects of multiple-beam interference, four-wave mixing and the asymmetry are controlled.

It should here be noted that the starting beam still could originate from both from an internal or external source. Further the same principle is valid for multiple amplifiers as bars or arrays.

The R_1 and R_5 like the R_2 and R_8 make both contributions to the vertical cavity normally seen as the one between R_1 and R_2. Therefore the ration between R_2 and R_5, and R_2 and R_6 can be used to control the amplification of the beams inside the diode.

This leads to the fact that a variant of this system can be build direct into a diode as seen in figure 5.2. Here different coatings or a hologram at the surface can make up the properties of R_5 and R_8.

Next step in the process of getting diffracted limited high brightness beam is the mode selective feedback.

<u>The Mode Selective Feedback</u>

The final step in getting a diffracted limited high brightness laser beam is the mode selective feedback.

As described above the existing modes is separated into space in the FFP. Therefore a spatial filter can be placed in the far-field or in a Fourier plane of a lens system. This feature prevent none selected modes to get extra gain from the feedback mirrors R_5 and R_6, whereas the modes passing the spatial filter is reflected back into the amplifier. This corresponds to get mode

03/04 '02 15:21 FAX +45 39 48 81 91 HB&B.LAR 026

03/04 '02 ONS 15:05 [AR/MT-NR 8388] 028

selective extra gain. The total energy present for amplification remains the same, therefore the none selected modes gets less gain and contributes therefore less to the total beam. In fact they never passes the spatial filter at the output. Is one mode selected only, the output beam will be a diffracted limits high brightness beam.

Figure 6.1. Selective Feedback

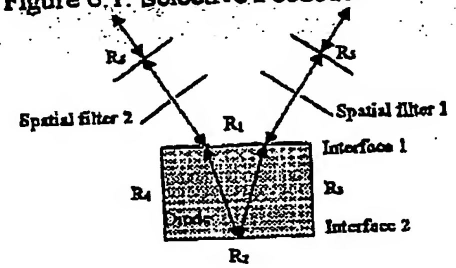
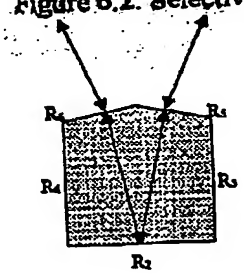


Figure 6.2. Selective feedback in diode



In the case of an internal system the mode selection is done by an angle depended coating or a hologram.

The outputs can either be two beams, if the reflective of R_5 and R_6 are low, or one beam, if either R_5 or R_6 have high reflectivity. Normal the one beam solution is chosen. One should notice here that that the mirror R_6 in some cases can be dropped.

The principles described above can be used on bars and arrays as well, as will be described below.

<u>Systems of Bars and Arrays</u>

The theories of this paper can work on bars and arrays of diodes, too. Here the input beams can originate from an external laser i.e. a single mode laser or a laser of the type described above. The beam used here has to be collimated. Then the angle of incidence will be the same for all emitters in the bare or array, which similar returns amplified beams including the selected mode or modes only.

Figure 7.1. Selective Feedback on a bar or array of standard diodes

03/04 '02 15:22 FAX +45 39 48 81 91 HB&B.L&R 027

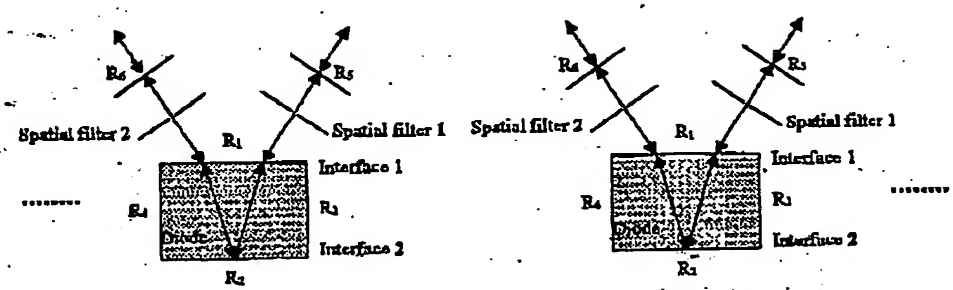
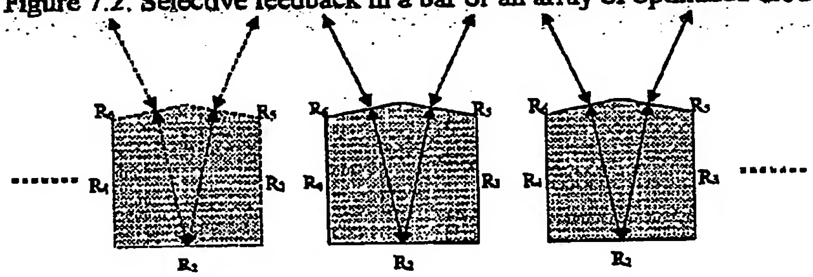


Figure 7.2. Selective feedback in a bar or an array of optimized diodes



The mirrors and spatial filters can of cause be common in then cases where diodes is placed in a setup, where the mode lines of the FFP have the same orientation.

If common mirrors or sources is used all diodes will synchronize to radiate in the same mode. In the case of mirrors i.e. the right side diodes left output on figure 7.1 or 7.2 will be reflected and becomes a right side input beam to the diode to the left and visa versa. This principle therefore works on multiple diodes.

One or several of the diodes of the bars or array can as well be used as the source of the selected mode. The diodes will always synchronize each other.

Incase where the FFPs not have the same orientation is the only requirement still that the diodes have to be synchronized. This will meanwhile be more complicated in practice but the principles and theories are the same. The important thing is effect described in this paper. The laser diode(s) is amplifier(s) only, therefore one can use as many as required by the amplification.

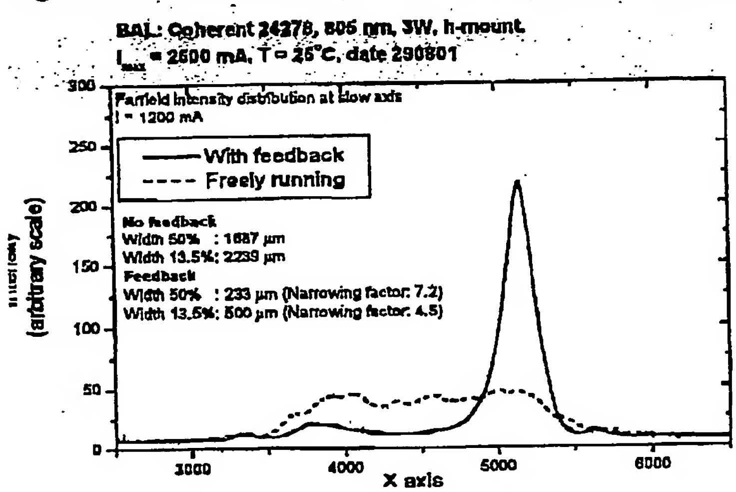
Next is shown if these principles are working in practice.

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 030

Experimental Results

By a primitive laboratory setup the effects of this paper can be shown to work in practice. On figure 8.1 the result of such an experimental work is shown.

Figure 8.1. FFP from experimental result. The diode equals the once described earlier.



The dashed curve is the FFP of the free running diode without the mirrors R_5 and R_6, and the spatial filters 1 and 2, with respect to figure 5.1. The solid line is the same diode with the FFP changed by feedback. Here the mirror R_5 and the spatial filter 1 and 2 are included only. R_5 is a high reflecting mirror. The curves are recorded between the diode and the spatial filters by the use of a wedge.

It is seen that highly asymmetry is introduced. Most of the power is now concentrated in the right side of the FFP. The power concentrated in the right peek measured on the backside of the spatial filter 2 has a power for 830mW. The total power of the whole FFP is 880mW. This is a conversion efficiency of above 90%

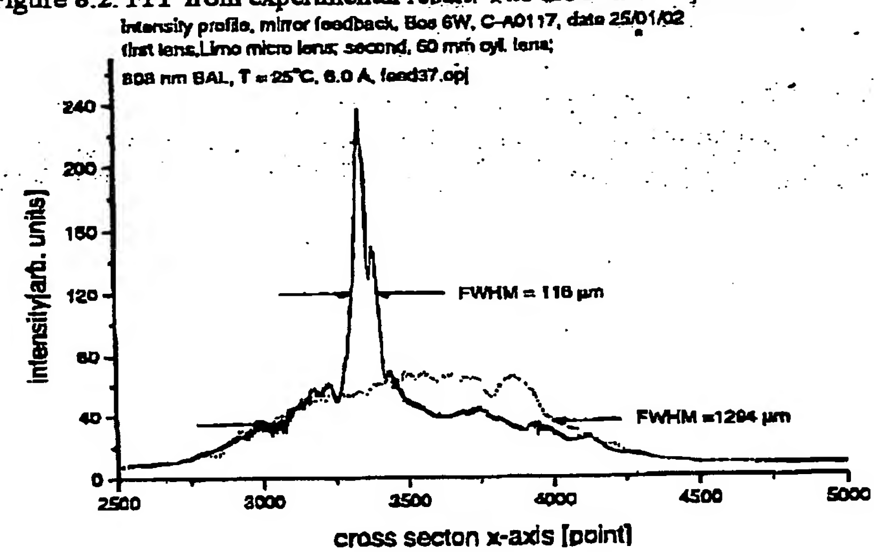
On figure 8.2 similar curves is shown for a 2000x390x2µm (LxWxH) diode at higher power.

This curve shows that the mode selective feedback principal works, notice that two modes exists within the curve with feedback. The power of this peak

-03/04 '02 15:23 FAX +45 39 48 81 91 HB&B.L&R 029

is 2.2W. The wavelength is 808 nm. And again the power is concentrated into a smaller spatial angle.

Figure 8.2. FFP from experimental result. The diode is 390 μm wide.



Hence, the measurements agree with the principles described above.

Hence, disclosed are the basic principles of the The Multiple Cavity High Brightness Diffracted Limited Diode Lasers. The principle included the combination of multiple-beam interference together with four-wave mixing, multiple cavities and selective mode feedback.

It has been shown also that this laser system is a real laser not a variant of an external cavity for laser diodes, because the laser diode is here an amplifier, only. Further the systems described her can be included directly into the structure of a laser diode as shown. Therefore this paper includes a description on a new type of diode laser system.

It has been shown that this theory agrees with experiments, and that this principle can be used on single stripe diodes, bars and arrays.

In the following an embodiment of the invention, referred to as GILAS laser, will be described.

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 032

Optical System for the GILAS Laser

The following sections include a basic description of the principles in the external cavity of the GILAS Laser and how the optical system inside the cavity works. Further it is explained why the optical system is designed as it is and a selection guide of specific optic elements is included, also. Comparison tables of the optics from different suppliers and the prices of the units are set up, too. The sections end up with a suggested cavity system and a view of its performance.

The GILAS External Cavity

The GILAS laser system needs an optical system to pickup as much power as possible from the light that radiates from a laser diode. At the same time this optical system have produce an image of the diodes far-field without introducing aberrations. The reason for an imaging with out aberrations is that far-field equals the Fourier-transform of the diodes near-field, the image of the surface where the diode radiates light. The near-filed and the far-field includes the many different modes that can exist inside the cavity of the diode. These many modes can exist because of the wide emitter stripe of the diodes. The number of modes depends of the geometry of the diode. Wide stripe diodes are required to get as high power out of the GILAS laser as possible. The many different modes are mixed up in space in the near-field region but in the far-filed region they are separated into space by an angular distribution. A single mode can therefore be located at a given position in space in the far-field region. It should here be noted that the diodes used for the GILAS laser only has one or a few modes in one direction and multi-modes in the other direction. An image of a near-field and a far-field can be seen in figure 9.1.

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03/04 '02 ONS 15:05 [AP/MT-NR 8388] 033

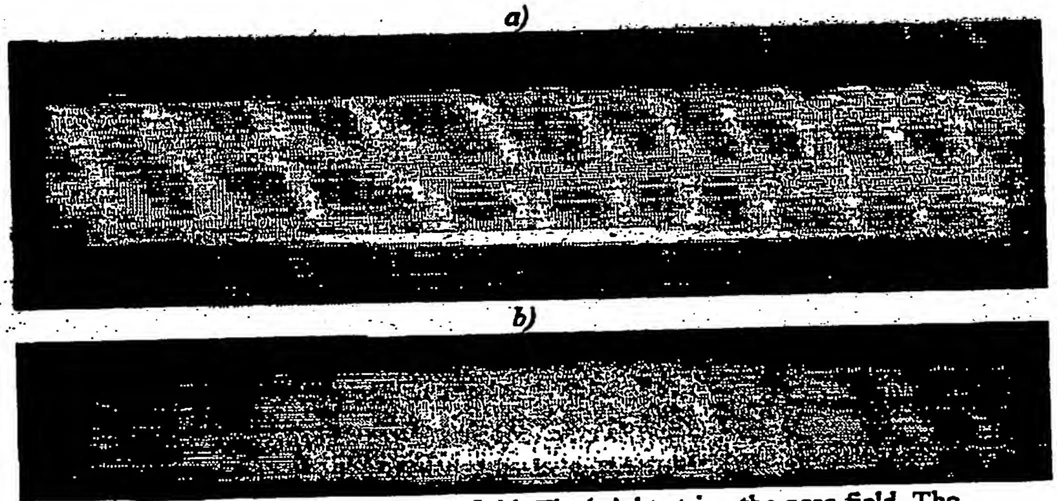


Figure 9.1. a) Image of a near-field. The bright stripe the near-field. The light rectangle is the wafer, 200µm. b) Image of a far-field in a distance of 400mm. Each horizontal line is representing one of the modes that exist in the multi-mode direction.

A god mode separation requires an aberration free imaging of the far-field, else the modes will be mixed up in space her, also. The idea of the GILAS laser system is to pick out one of these modes and feed it back into the laser cavity. Hereby this one mode is amplified more inside the cavity than the rest for the modes. This results in die out of all the other modes and a mass population of the selected mode, just as know from the theory of evolution.

The best mode to select for feedback can be different from diode to diode. In some free running diodes all modes have the same gain, whereas other diodes have a one or a few favourite modes that have a higher gain than the other modes. In the last case one is not free to select any of the modes, only the once with the high gain can be used. In the other case any mode can be selected but the best result will always come from the modes at the top or the bottom edge of the far-field, with reference to figure 1. This is caused by the fact that these modes have to travel a longer distance inside the cavity of the diode, thereby their probability of being amplified are higher than for it is for the rest of the modes.

The result of the one mode feedback is that a multi-mode laser beam with a beam quality $1<<M^2$ transforms into a single-mode laser beam with a beam

03/04 '02 15:24 FAX +45 39 48 81 81 HB&B.LAR 032

quality $M^2 < 2$. A beam with $M^2 < 2$ can be focused into a spot-size less that 10μ, which are one of the requirements to the GILAS laser. This transform will in some cases only reduce the total power by about 10%. The transformation loss and the reached beam quality are here very depended on the profile of the far-field. A square like far-field profile, which equals the case where all modes have the same gain, is predicted to give the best results.

The above description leaves three optical problems to be solved: First, how to make the Fourier-transforms of the near-field and then selected a single mode, and afterwards feed back this one mode into the laser diode. Second, how to pickup as much power from the diode as possible without introducing aberration into the imaging of the far-field. Third, how to make this optical system with a loss of power that are as small as possible.

Mode Selection by a Fourier-Filter

The far-field can exist in to cases: Either in a distance from the diode that is much larger that the dimensions of the near-field it self, or in a narrow distance around the image point of a lens or a system of lenses. Lenses can not be avoid in this case because of the requirement of picking up power, so the far-field must be placed in an image point of a lens or a system of lenses

The filtering of a far-filed is known problem that is offen solved by use of a Fourier-Filter. A classical Fourier-filter can be build up of two lenses and a spatial filter as seen in figure 9.2a.

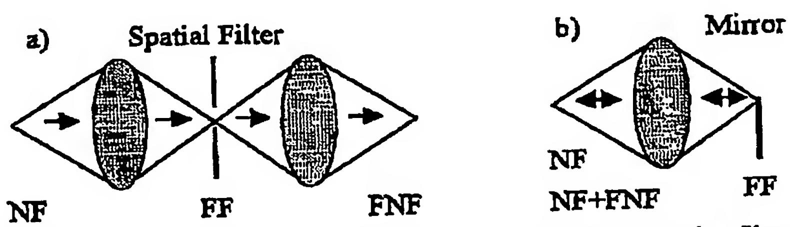


Figure 9.2. a) A classical Fourier-Filter. b) GILAS Fourier-filter.

03/04 '02 ONS 15:05 [AP/MI-NR 8388] 035

In the classical Fourier-Filter the near-field NF is Fourier-transformed into the far-field FF by the lens to the left. In the FF is a spatial filter applied. Thereby is the filtered near-field FNF, constructed by an inverse Fourier-transform by the lens to the right. In the GILAS laser the filtered near-field has to be feed back into the original beam. This done by a developed variant of the Fourier-Filter called a GILAS Fourier-Filter. Here the second lens and the spatial filter are substituted with a thin mirror stripe with very sharp edges. The width of the mirror stripe has to equal the width of the selected mode in the position of the far-field. This mirror will then feed back the selected mode, only. The first lens is here doing both the Fourier-transform and the inverse Fourier transform. Because of the mirror feedback the GILAS laser is turned into a variant of an external cavity laser.

The GILAS Fourier-filter have bee tested and is found to work very well. At the moment the Fourier-filter has been used with none aberration free optics in a none ideal set up, only; therefore it is expected that better results can be reached with the aberration free optic system described below.

Aberration Free Optics

A major problem in picking up the power from the laser diode is that the beam is very different and highly divagating in two directions. The two directions are known as the fast-axis, divergence at around 35°, and the slow-axis, divergence at around 10°. The fast-axis includes only one or a few close placed modes, which results in a Gauss like far-field profile in this direction. The slow-axis includes on the other hand many modes and its far-field profile is far from a Gaussian-shape. This shape can vary from a square shape to a shape of the Alps. A significant difference in the field of view of the two directions exists, also. The fast-axis is only a 1-2μm wide whereas the slow-axis is 150-1000μm wide. This returns the classical problem of making a god imaging of a very long and thin pole. Because of these large differences in the properties of the two axes one have to introduce cylindrical optics, so one direction can be treat at time, only.

Normal spherical optics is introducing large spherical aberration onto beams with a high angle of divergence. Therefore one have to use corrected

03/04 '02 15:26 FAX +45 39 48 81 91 HB&B.L&R 034

cylindrical optics, which is difficult to produce and therefore highly expensive; a minimum use is therefore recommended. Another option is to use both spherical and cylindrical lenses in a combination of several lenses. This is cheaper and less effective but this can bring the spherical aberrations down by around a factor of 10 by the use of two lenses instead of one. Here one has to be aware that every surface in such a system will introduce a loss of power; high power is a very critical point in the GILAS laser, so as few lenses as possible is required.

The most critical axis is the fast-axis because of its high divergence and the fact that the GILAS systems not are able to improve the beam quality in this direction in any way. The only thing the GILAS system can provide to this direction is aberrations; therefore it is of highest importance to treat this direction as god as possible. For picking up the beam in this direction and transform it into a parallel beam it is chosen to use a standard highly corrected, 12th order, micro cylindrical lens. This will in some degree keep the costs of the system down. Some possible choices are:

Company	*Order. Code*	*Focal length [mm]*
Limo	*FAC 850*	*0.09107*
Limo	*FAC 850D+*	*0.09107*

The D+ is a better quality with a coating for 808nm.

The next thing is to decide the length of the external cavity. On the one side a very short cavity is wanted because of the space requirements, on the other side a long cavity can reduce the aberrations and standard spherical optics can be used in a higher degree. To bring down the requirements for positioning of filter-mirror and the sharpness tolerances of the mirror edges a cavity length of 100mm is selected. This is caused with the respect to a need of a magnification of far-field image, also. A high density of power can introduce damages to the surface for the mirror. Further it will be easier to do the mode selection on a magnified image. A magnification of five is here reasonable.

The fast-axis part of the laser beam should after the first cylinder lens be collimated. To produce an image point in the distance of the cavity length the

beam has to be focused. To minimize aberrations an achromat lens is selected for this purpose. The achromat is selected as a rotation symmetric lens that will work commonly for both axes. Some possible choices are:

Company	Order. Code	f [mm]	Ø [mm]
Opto Sigma	026-0680	80	25
Melles Griot	01 LAO 011	80	25
Linos	322210	80	25

All lenses are coated for 830 nm.

The Opto Sigma lens was chosen with a special coating A58 with R<0.2% in the range 800-850nm.

This achromat is placed close to the fast-axis collimation lens to get a high magnification, around 10 times. A little space between the two lenses is still left over; thereby the cylindrical pick up lens for the slow-axis direction can be placed in between. This results in a very compact lens system with a total length of 30mm. The slow axis cylindrical lens is build up of two cylindrical lenses to minimize the aberrations and to get the possibility for getting an effective variable focal length outside the standard available once. Changing the spacing of the lenses, normally 1 to 3 mm, changes the effective focal length. A focal length of 25mm and 20mm are selected to place the slow-axis focal point at the same position as the one for the fast-axis. It should here be noted that the slow-axis not have been collimated at any position. The magnification is the slow-axis ends up to be 5.25.

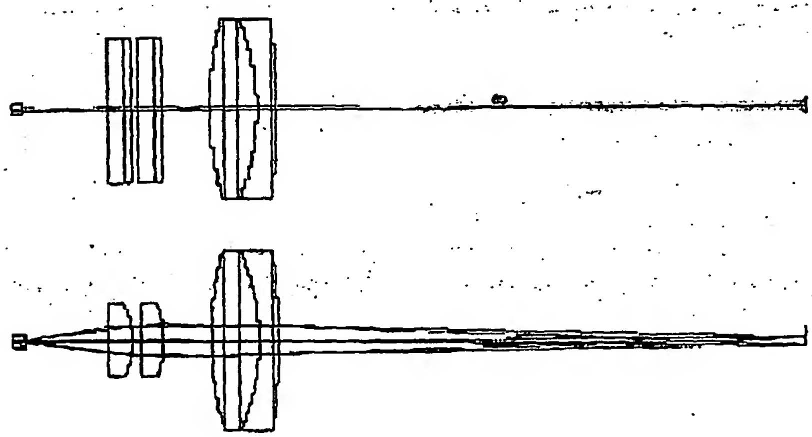
Possible choice of lenses in this case is manly lenses from Linos or Opto Sigma lenses.

Company	Order. Code	f [mm]	HXB [mm]
Opto Sigma	022-0140	20	10x20
Opto Sigma	022-0170	25	10x20
Opto Sigma	022-0240	30	10x20

All lenses these have to be coated for 830 nm.

The Zemax software did a simulation of the system. The angle of divergence was chosen to be worst case, 45° for the fast-axis and 16° for the slow-axis. The return of the Zemax ray tracing is seen in figure 9.3.

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 038

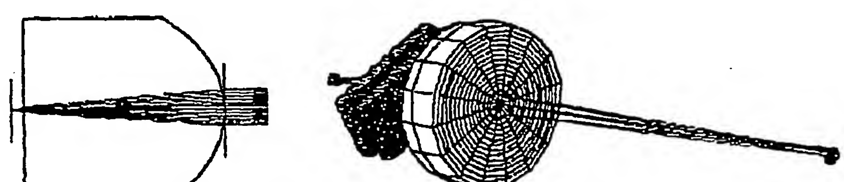


a)

b)

Figure 9.3. a) Tray-tracing in the fast-axis direction, the emitter height is assumed to be 2μm. b) Tray-tracing in the slow-axis, the emitter width is 500μm. Different colours correspond to different staring points of the beam, see figure 9.4.

At figure 9.3 the GLAS Fourier-Filter will be placed at the vertical line to the right. The diode it self is so small that it cannot bee seen at the image, but it known to exist to left of the fast-axis cylinder lens in the left side of the picture. A zoomed image of the fast-axis cylinder lens can be seen in figure 9.4.



a) b)

Figure 9.4. a) A zoomed image of the fast-axis cylinder lens. b) 3D image.

The performance of the optical system regarding the optical path differences, spherical aberrations, is plotted in figure 9.4.

It is seen from figure 9.5 that the system can reach the theoretical, limit 0.25λ, of an aberration free, diffraction limited, system. In this simulation the width of the emitter width was 2x500μm. It is know that the emitter size in the future can be larger i.e. 1x700μm or even more. The OPD of the same configuration can for a 2x1000μm emitter come below 0.3λ. Note, that the

03/04 '02- 15:28 FAX +45 39 48 81 91 HB&B.L&R 037

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 039

angle of divergence is chosen to worst case for this simulation. In practise this system should be enough, else cylinder lens pair for the slow-axis can be replaced be one special designed aspherical cylindrical lens. This can easily bring down the aberrations to the size of the once seen at the fast-axis; this limit here is only set by money. The length of the cavity can be enlarged to keep down prices, also. Thereby should this system include the use with wide single stripe diodes, segmented single stripe diodes and laser diode bars.

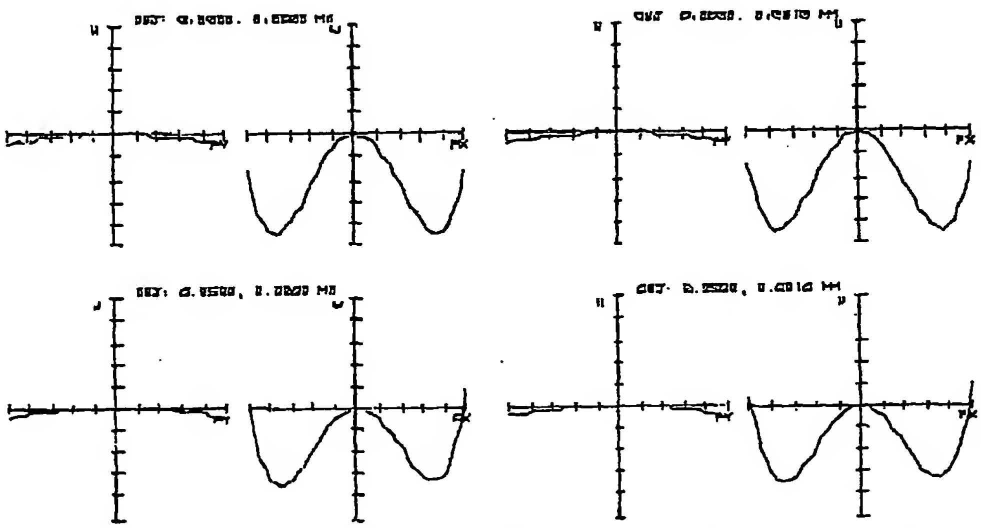


Figure 9.5. Plot of the optical path differences, spherical aberration. Lefts fast-axis. Rights slow-axis. Top-Left) centre of slow-axis and centre of fast-axis. Top-Right) Centre of slow-axis and edge of fast-axis. Bottom-Left) Edge of slow-axis and centre of fast-axis. Bottom-Right) edge of slow-axis and edge of fast-axis. Scale ±0.2λ.

In one embodiment of the invention a modulated, intensity controlled laser beam is supplied, e.g. for use in an internal drum image setting machine.

The laser beam is produced by one wide single stripe laser diode with the GILAS external cavity extension as described above, or with two or more of these systems in a polarization coupling. The system according to this embodiment modulates the laser beam from the diode through an acousto-optics amplitude modulator (AOM) to produce pulses of laser light with a well-defined period. Also, the voltage applied to the acousto-optics crystal may be controlled by a feedback from a photo detector before the AOM to

03/04 '02 15:28 FAX +45 38 48 81 81 HB&B.L&R 038

03/04 '02 ONS 15:05 [AF/MT-NR 8388] 040

ensure a uniform density of the exposed areas. Preferably, it is ensured that the power of the beam can be turned down to a level below the level of plate exposure of the image setter to prevent accidental exposure of the plate/film in areas where it is not wanted.

It is further noted that the laser system according to the invention may also be used in connection with frequency doubling in order to achieve a high power laser beam with good coherence properties at higher frequencies.

03/04 '02 15:28 FAX +45 38 48 81 91 HB&B,L&R 039

CLAIMS

1. A laser system comprising
- an amplifier member including an amplifying medium;
- a first reflective member located on a first side of the amplifier member; and
- a second reflective member located on a second side of the amplifier member opposite the first side;

characterised in

that the laser system further comprises a third reflective member located on the second side of the amplifying member and, during operation, cooperating with the second reflective member to control the spatial intensity distribution of the light distribution in the amplifying medium in a direction along the first and second sides of the amplifier member.

2. A laser system according to claim 1, characterised in that the reflectivity of the second reflective member is different from the reflectivity of the third reflective member and the ratio of the reflectivities of the second and third reflective members is adapted to increase the intensity of a dominant mode of the emitted light distribution.

3. A laser system according to claim 1 or 2, characterised in
- that the first reflective member is a reflective coating on the first side of the amplifier member;
- that the second and third reflective members have respective second and third normals each having a component parallel to the first side, the parallel component of the second normal having a direction opposite to the direction of the parallel component of the third normal.

4. A laser system according to any one of claims 1 through 3, characterised in that the system further comprises a first and a second spatial filter, the first spatial filter being located between the amplifier member and the

second reflective member, and the second spatial filter being located between the amplifier member and the third reflective member.

5. A laser system according to any one of claims 1 through 3, characterised in that the second side comprises a first area and a second area forming an acute angle with the first area and the second and third reflective members are respective coatings on the corresponding first and second areas.

Laser system

Abstract

Disclosed is a laser system comprising an amplifier member including an amplifying medium; a first reflective member located on a first side of the amplifier member; and a second reflective member located on a second side of the amplifier member opposite the first side. The laser system further comprises a third reflective member located on the second side of the amplifying member and, during operation, cooperating with the second reflective member to control the spatial intensity distribution of the light distribution in the amplifying medium in a direction along the first and second sides of the amplifier member.